Development of dual-tuned knee coil at 7T: a feasibility study of high-resolution sodium MR imaging and T2 mapping in knee cartilage in vivo

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Introduction: Sodium MR imaging has been proposed as a means for the early assessment of loss of proteoglycan (PG) contents in knee osteoarthritis (OA). Despite the promising features, sodium MR imaging remains challenging due to an intrinsically low MR signal and the requirement for a high-sensitive dual-tuned RF coil. Several studies have established the feasibilities of sodium MRI to assess the progress of knee OA [1, 2]. In addition to the biochemical information obtained from sodium measurement, the morphological information of knee cartilage is essential to assess the progress of OA [3, 4]. In this study, we developed a dual-tuned (DT) proton/sodium knee coil with high B_1 field homogeneity for both nuclei at 7T, and demonstrated high-resolution sodium MR imaging and T_2 mapping of human knee in vivo.

Material and Method: All scans were performed on a 7T scanner (Siemens Medical Solutions, Erlangen, Germany). Two normal subjects were scanned in this IRB approved study. An in-house DT knee coil (**Fig. C**) consisting of a 4-channel sodium transceiver (T/R) coil **(Fig. 1A)** and hybrid birdcage proton coil (**Fig. 1B**). To isolate each nuclei coil, two band-rejection filters were inserted in each sodium coil loops. For proton MR imaging, 3D dual echo steady state (DESS) sequence was used to acquire high-resolution anatomical image (**Fig. 2A**). Scan parameters were: TR/TE = 15/5 ms; flip angle = 25°; slice thickness = 0.8 mm; FOV= 200 × 200 mm^2; matrix = 256 × 256; and total acquisition time (TA) = ~7 min. For sodium MR imaging, 3D ultra-short echo time (UTE) spiral sequence [5] was used for 1) T2 mapping; TR/TEs = 150/0.5 - 80 ms, flip angle = 90°, resolution = 3 mm^3, and TA for each TE = 1:30 min, and 2) high-resolution sodium MR imaging; TR/TE = 120/0.5 ms, flip angle = 90°, resolution = 2 mm^3, and TA = ~6 min with 3 averages. Two different homogeneous phantoms (saline with 75 mM [^{23}Na] and 4% agarose with 30 mM [^{23}Na]) were scanned for testing coil performance. Signal-to-noise ratio (SNR) and sodium T_2 relaxation time were measured from homogeneous phantoms and human knee sodium images (**Fig. 2**). T2 mapping was done by signal fitting to the bi-exponential equation, $a*\exp(-TE/T2_{intra}) + b*\exp(-TE/T2_{extra})$ in pixel-by-pixel basis (**Fig. 2C**).

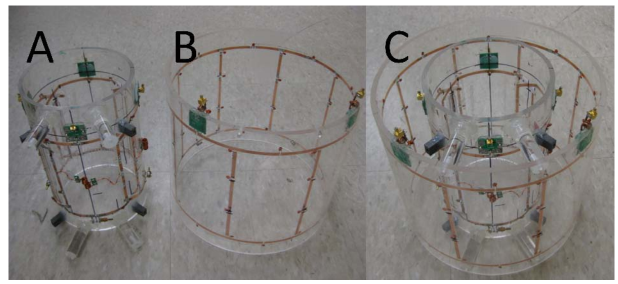

Fig. 1 Dual-tuned knee RF coil for 7T. **A,** Four-channel sodium coil (140 ×180 mm^2). Six capacitors were distributed and neighboring loops were overlapped to decouple whereas inductively decoupled with non-adjacent loop. **B**, Hybrid birdcage proton volume coil (diameter 295 mm, height 180 mm). Eight lungs with 4 distributed capacitors in each lung and eight capacitors at each end rings. **C**, Assembled dual-tuned knee RF coil**.**

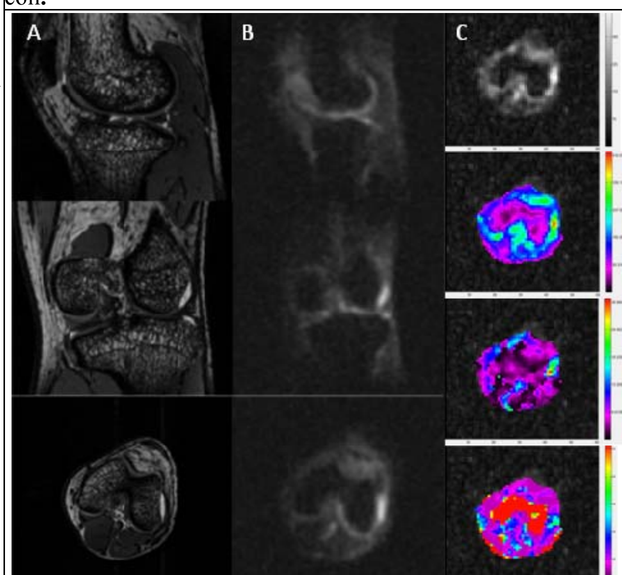

Fig. 2 In-vivo proton and sodium MR imaging of normal human knee. **A**, Proton DESS MR image; sagittal, coronal, and axial view. **B**, Corresponding sodium MR images. **C**, T2 map in axial view - sodium density (first two rows), intra-cellular sodium and extra-cellular sodium T2 from top to bottom.

Results and conclusions: We obtained relatively homogeneous proton and sodium MR imaging using a newly developed DT knee coil at 7T (**Figs. 2A** and **B**). SNR in a homogeneous 75-mM saline phantom was measured as 45 in both inner and outer ROIs, and those in three knee cartilages were from 26 to 34 (**Table 1**). The sodium T2 relaxation time measured ~43 ms over 75-mM [^{23}Na] saline, and the intra- and extra-cellular T2 in 4% agar with 30 mM [^{23}Na] measured 4.12 ms and 13.8 ms, respectively. In addition, the intra- and extra-cellular T2 values in normal human cartilage measured 5.4 ms and 17.4 ms, respectively (**Table 1**). High-resolution knee sodium MR images (co-registered with proton MR images) demonstrated clear demarcation of cartilage compartments **(Fig. 2B)**.

Table 1. SNR and T2 measurement in the three cartilages.

	Patella	Tibia	Femur
Mean SNR	26	31	34
Mean intra-/extra-cellular T2 (std) [ms]	4.8/16.5 (1.6/5.5)	6.7/15.3 (2.2/2.7)	4.6/20.3 (2.5/5.6)

In conclusion, we obtained high-resolution, high-SNR sodium MR imaging of human knee using an in-house DT knee RF coil at 7T scanner. Our proton/sodium MR images illustrated clear demarcation of knee cartilages and the feasibility of T2 relaxation time mapping of knee cartilages in vivo within reasonable time (< 15 min). Further studies on B_1 phase shimming in sodium MR imaging are necessary to improve homogeneity of B_1 field. Additionally, accurate and reliable measurements of sodium concentration and T2 of knee cartilage in vivo should be investigated.

References: [1] Shapiro et al. *JMR*, p24-31 (2000). [2] Madelin et al. *JMR*, in press (2010). [3] Watkins et al. *ISMRM* (2010) [4] Kim et al. *ISMRM* (2010). [5] Zhao et al., *ISMRM* (2009).